Specialty grouting techniques: Technical considerations and applications in Canada

Naresh Gurpersaud, Daniel Lees & Zhong Han
Keller Foundations Ltd, Acton, ON, Canada

ABSTRACT
Challenging geotechnical conditions are commonly encountered during construction activities due to the highly variable nature of soils and rocks. Excessive water inflows or variability in soils or rocks can result in numerous challenges during the construction of dams, tunnels, shafts, cut-off walls, structures, etc. Specialty grouting strengthens target areas in the ground and controls groundwater flow through rocks and soils by reducing their permeability. Most grouting applications can be performed in situ and targeting areas where treatment is required. The degree of improvement can be evaluated by real-time quality control and this type of work is performed by highly skilled and experienced personnel. Speciality grouting can be tailored to suit the actual conditions encountered during the execution of the work. The desired strength and/or permeability can be achieved by using stringent quality control measures. An overview, including technical considerations and case histories of a few speciality grouting applications such as jet, compaction, rock fissure and permeation grouting are outlined in this paper.

RÉSUMÉ
Des conditions géotechniques difficiles sont fréquemment rencontrées lors des travaux de construction en raison de la nature très variable des sols et des roches. Les apports excessifs d'eau ou la variabilité des sols ou des roches peuvent entraîner de nombreux défis lors de la construction de barrages, de tunnels, d'arbres, de murs coupés, de structures, etc. Le jointage spécialisé renforce les zones cibles dans le sol et contrôle le flux d'eau souterraine à travers les roches et les sols en réduisant leur perméabilité. La plupart des applications de jointement peuvent être exécutées in situ et cibler des zones où le traitement est nécessaire. Le degré d'amélioration peut être évalué par le contrôle de qualité en temps réel et ce type de travail est effectué par du personnel hautement qualifié et expérimenté. Le jointage de spécialité peut être adapté aux conditions réelles rencontrées lors de l'exécution de l'œuvre. La force et/ou la perméabilité souhaitées peuvent être obtenues en utilisant des mesures rigoureuses de contrôle de la qualité. Un aperçu, des considérations techniques et des antécédents de cas impliquant quelques applications de jointage de spécialité telles que le jet, le compactage, la fissure rocheuse et le jointage de perméation sont décrits dans cet article.

1 INTRODUCTION

Challenging geotechnical conditions are commonly encountered during construction activities due to the highly variable nature of soils and rocks and limitations on geotechnical studies to accurately depict the global ground condition. Low cohesion soils and excessive water inflows or variability in soils or rock can result in numerous challenges during the construction of dams, tunnels, shafts, cut-off walls and structures.

Specialty grouting can strengthen target zones in the ground and control groundwater flow through rocks and soils by reducing their permeability. Grouting applications are typically performed in situ and targeting areas where treatment is required using a surgical approach. The degree of improvement can be evaluated by real-time quality control and this type of work is typically performed by highly skilled and experienced personnel. Real-time quality control is paramount when applying a technology where the active process cannot be directly confirmed by visual inspection.

This paper presents an overview of several specialty grouting techniques, including jet grouting, compaction grouting, rock fissure and permeation grouting, in terms of their application and basic principles. Several case histories of specialty grouting applications in Canada, particularly in Ontario, are summarized and illustrated to demonstrate the essential components of successful delivery, performance and verification of specialty grouting.

2 JET GROUTING

2.1 Application

Jet grouting is a ground improvement method that can be used for underpinning, water control, earth retention, and other geotechnical challenges. Jet grouting is well-suited for sites which are deemed challenging due to restricted access, work being performed below the groundwater elevation or requiring targeted treatment. It is effective across a wide range of soil types, including granular soils, silts and most clays, making it one of the most versatile grouting techniques (Kirsch and Bell, 2013).

Jet grouting is an erosion-based process with simultaneous blending/partial replacement of existing soils with cementitious grout that can be used to construct a variety of geometries, from thin vertical panels to sector (partial) columns, to full columns of varying diameters. Further, soil-cement properties (i.e. strength, hydraulic conductivity) can be modified by controlling various grouting parameters. Parameters that can be modified include drill rod extraction rate, rotation speed, grout pumping pressures, grout flow, and the specific gravity of the grout. The equipment can be sized to accommodate project needs ranging from low-headroom applications to treatment depths exceeding 30m. This flexibility enables the technique to be tailored to meet the specific project requirements.

The jet grouting process can be used to treat targeted soil strata at depth without disturbing the soils above it. Additionally, because the mixing occurs with fluid and not with a mechanical tool, this allows for treating against, below and around existing structures, such as a bulkhead, shaft wall, or concrete pipe (Kirsch and Bell, 2013). The drill rigs used for jet grouting comes in a range of different sizes; large rigs capable of efficiently treating to depths over 30m and mini-rigs capable of walking through a 0.76 m wide door and working in a basement with only 2m of headroom, making it a perfect technique for improving the foundation of an existing structure.

2.2 Design and execution considerations

The jet grouting process uses specialty drill tooling which includes a grouting monitor attached to the end of a multi-chamber drill stem. Typically, the monitor is advanced to the targeted treatment depth, at which time high velocity/energy grout jets typically shrouded with air (and sometimes water) are initiated through nozzles on the side of the monitor. Figure 1 shows a schematic of jet grouting. The jets simultaneously erode and mix the in-situ soil with a cementitious binder as the drill stem and jet grout monitor are rotated and retracted. The process continues until the upper limits of the treatment zone are reached, at which time the tooling is withdrawn, and the hole backfilled with cementitious grout.

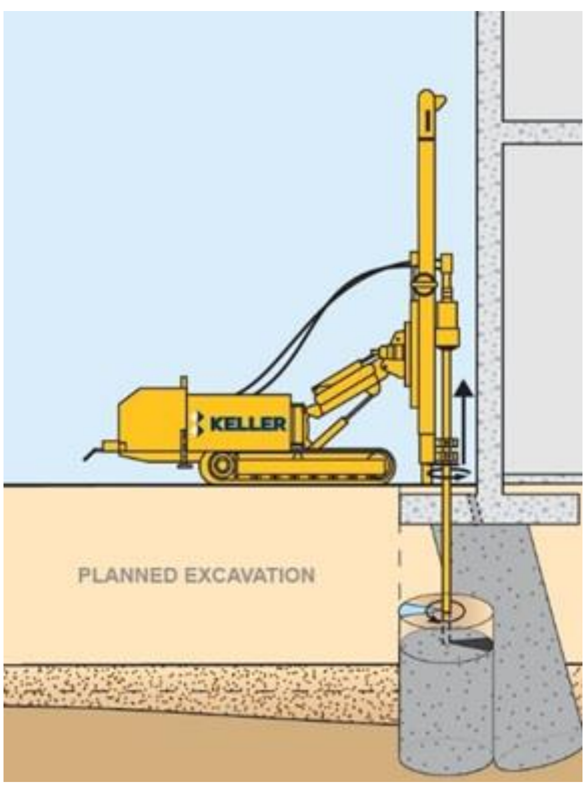

Figure 1 Schematic of jet grouting

Depending on the geometry requirements, the monitor can be rotated continuously in the same direction to create a column or rotated partially back and forth to create any portion of a full 360º circular geometry. The monitor can also be held static as it is withdrawn to create panels in the targeted soil formation. Figure 2 shows typical jet grouting equipment and installation process.

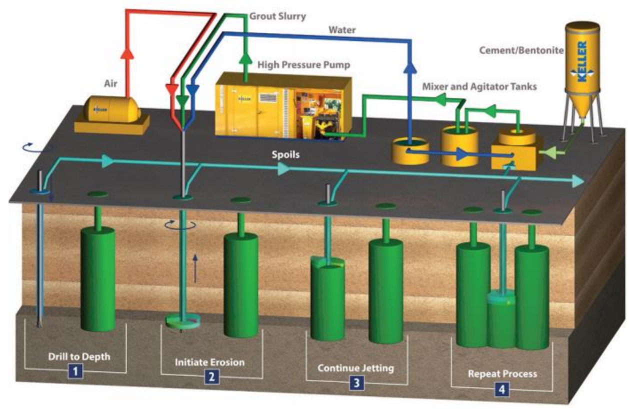

Figure 2 Jet grouting equipment and process

The diameter of the created soilcrete column is a function of the erosional energy of the jet, erodibility and quantity of the soil. The jetting energy is controlled by the grout flow, grout pressure and tooling lift rate. The grout flow and pressure are adjusted by varying the diameter of the fluid nozzles. The withdrawal rate can also be changed to increase or decrease the diameter of the jet grouted column. In general, the more granular and cohesionless the soils are, the greater the erodibility. Gravels, however, can be difficult to assess. They can be either easily eroded or problematic to erode based on the geologic depositional process in which they were placed.

The strength and hydraulic conductivity of the soil-cement are both functions of the binder content and type of soil treated. The more granular or less cohesive the soils, typically the higher the strength. Higher binder contents can also yield lower hydraulic conductivities in certain soil types. The binder content can be modified by adjusting the specific gravity of the grout used in the jetting process. additionally, Ground Granulated Blast Furnace Slag (GGBFS) can be used as a binder and bentonite as an additive, which will typically provide lower hydraulic conductivities than Portland cement.

Jet grouting can be classified under 3 categories : single, double and triple fluid. Single fluid involves the injection of cementitious grout only through the nozzles. The double fluid is similar but incorporates an air shroud around the cementitious grout which improves erosion and evacuation of spoils. Triple fluid uses two sets of nozzles, the upper nozzles inject water with a shroud of air to perform the erosion and the lower nozzles inject cementitious grout to replace/blend the eroded soil to create the column.

2.3 Case history: Use of jet grouting to create water-tight excavation at West Don Lands, Toronto

The West Don Lands, an area of approximately 32 hectares located east of downtown Toronto, lies adjacent to the Don River. The transformation from a brownfield site into a mixed-use riverside community required a Flood Protection Landform (FPL) and the FPL's backflow preventer, which were constructed next to an existing bridge crossing the Don River.

The backflow preventer was built in a chamber that surrounded a portion of the existing 1650 mm diameter sewer that drains into the Don River. Support of the existing ground outside the footprint of the chamber required sheet piles. Difficulties were encountered throughout the installation, including the detection of movement of nearby bridge piers which postponed further work. With the excavation support work only partially completed and a new embargo placed on dewatering during excavation, jet grouting was selected for its ability to provide a base seal and improve the ground at the two terminal ends of the chamber excavation.

A jet grout base plug and vertical cut-off were designed and installed to enable the excavation to proceed. Figure 3 shows the structure of the backflow preventor excavation that was created by jet grouting technique. The double fluid jet grouting system was used to construct overlapping jet grout columns. Cement grout and compressed air were delivered separately to the tip of the grout hole via double-wall concentric drill rods. At depth, during grouting from the bottom upwards, grout was injected at high velocity surrounded by a shroud of air. This combination of fluids aids in cutting and mixing, with the result being large diameter jet grouted soilcrete columns.

At the West Don Lands project, constructing overlapping columns created diaphragms of strengthened soil with dramatically reduced hydraulic conductivity. A total of 46 no. overlapping jet grout columns, located 12 m to 9 m below surface, make up the 10 m x 7 m base plug. The vertical cut offs, arranged at each end of the excavation where the presence of the existing sewer precluded driving sheet piles, consists of 12 no. overlapping, battered jet grout columns 10.5 m long, located 12 m to 1.5 m below surface.

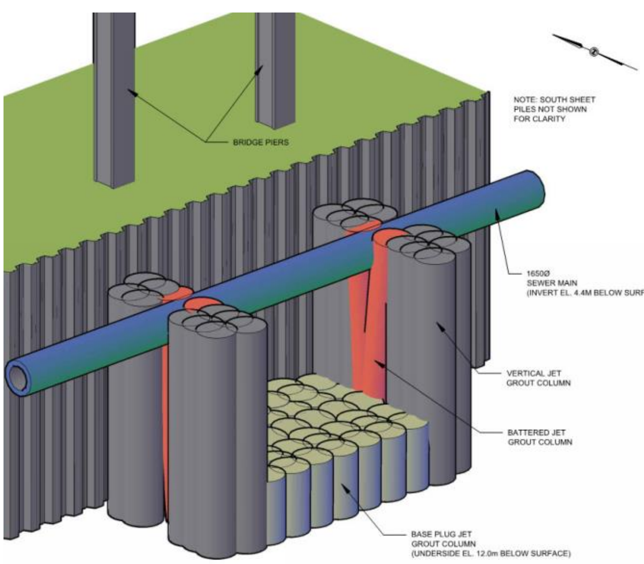

Figure 3 Profile of excavation created by jet grouting

3 COMPACTION GROUTING

3.1 Application

Compaction grouting is a ground improvement technique that improves the strength and/or stiffness of the ground by slow and controlled injection of a low mobility grout (25 to 75mm slump). Compaction grouting is a bottom-up system similar to jet grouting. A casing must be advanced to final depth and is then extracted through the target zone while injecting low mobility grout. The soil is displaced and compacted as the grout mass expands (see Figure 4). Provided that the injection process progresses in a controlled fashion, the grout material remains in a growing mass within the ground and does not permeate or fracture the soil (CFEM, 2006).

This behavior enables consistent densification around the expanding grout mass, resulting in stiff inclusions of grout surrounded by soils of increased density. The process can be applied equally well above and below the water table. It is usually applied to loose fills and native soils that have sufficient drainage to prevent the buildup of excess pore pressure. Injection rates must be controlled to allow pore water dissipation and thus prevent hydrofracturing of the soils.

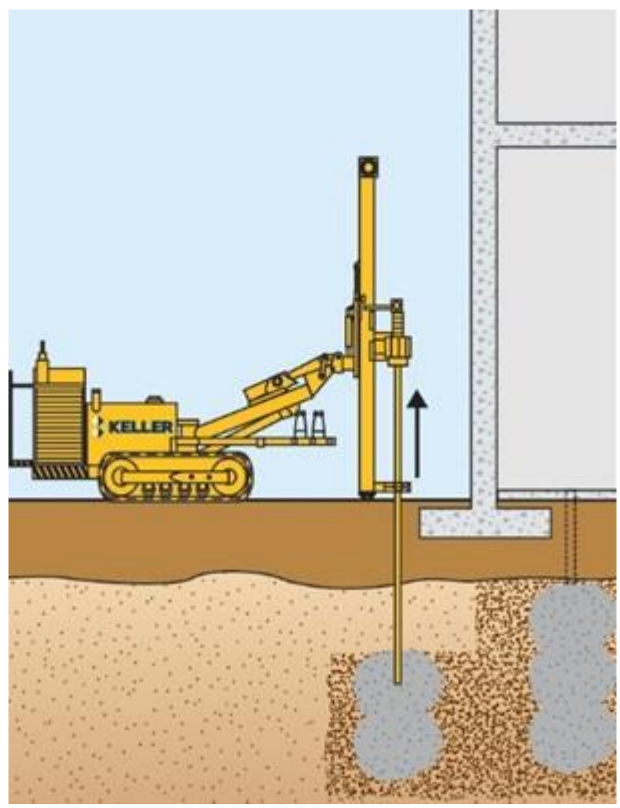

Figure 4 Schematic of compaction grouting

Compaction grouting can be used for the following applications:

- Pre-construction soil improvement to support shallow foundations;
- Compaction of loose fills;

- Creation of grout columns and filling voids within loose or deteriorating natural soil conditions (i.e., organic degradation, etc.) or voided fills;
- Compaction of loose soils resulting from adjacent excavation activity, tunneling, sinkhole activity, improper dewatering, broken utility lines etc.;
- Compaction to increase bearing capacity or reduce potential settlement beneath existing foundations when modifications to the existing structure increase the foundation loading;
- Compaction of the deep loose zones;
- Improvement of ground between pinnacled limestone to avoid deep piling within slots;
- Injection of grout beneath settled structures to heave and relevel the structures;
- Increasing lateral support for existing deep foundations;
- Injection of grout to compensate for ground movements arising from underlying tunneling operations or near deep excavations.

3.2 Design and execution considerations

In order to perform compaction grouting, comprehensive knowledge of subsurface conditions is important. To prepare a suitable program, a geotechnical investigation is necessary to reveal the site geology and history, soil gradation, and the in situ horizontal permeability. Type and condition of nearby structures and utilities is critical information to prevent causing damage during the execution of the work (Kirsch and Bell, 2013).

The following are important considerations while designing a compaction grouting project:

- The in situ vertical stress in the treatment stratum must be sufficient to enable the grout to displace the soil horizontally (if uncontrolled heave of the ground surface occurs, densification will be minimized);
- When compaction grout is injected into saturated soils, a pore pressure increase occurs as a result of ground displacement. This increased pressure must dissipate for effective densification to take place. Therefore, the grout injection rate should be slow enough to allow pore pressure dissipation. Sequencing of grout injection is also important;
- Compaction grouting can usually be effective in most silts and sands, provided that the soil is not near saturation;
- Soils that lose strength during remolding (saturated, fine-grained soils; sensitive clays) should be avoided;
- Greater displacement will occur in weaker soil strata. Excavated grout bulbs confirm that compaction grouting focuses on improvement where it is most needed;
- Collapsible soils can usually be treated effectively by adding water during drilling prior to compaction grouting;
- Stratified soils, particularly thinly stratified soils, can be cause for difficulty or reduced improvement capability.

Typically, greater than 70 kPa overburden stress is required to maximize densification. Limited densification can be achieved with less overburden. This stress can come from overburden soils, surcharge loads and/or foundation loads.

Experience has proven that treatment spacing should not exceed 1.8 to 3m. The hole spacing can be used to estimate a compaction grouting volume. The maximum pressure criterion prevents fracture and ground heave and compensates for stiff zones in the treatment area. Vertical stages are usually set at 0.6 to 1.5 m intervals; tighter grid spacing will generally lead to better results. Setting a grid grouting pattern and split spacing sequence will demonstrate consistent and demonstratable soil improvement.

3.3 Case history: Compaction grouting to mitigate manhole collapse at Jane Street and Highway 7, Vaughan, Ontario

The intersection of Jane and Highway 7 in Vaughan, Ontario was closed from February to May, 2006 after a manhole within the intersection collapsed and caused a water main to break. The eventually vast scope of repairs at this site, which included multiple deep excavations and several completely reconstructed sewers, included compaction grouting to restore density and stiffness to a disturbed soil layer beneath the intersection.

The manhole collapse was caused by long term migration of fine soil particles through a breach in a deep sewer pipe that passed through a sandy soil layer well below the water table. From the time the sewer pipe breached until the manhole collapsed, the sewer was effectively acting as a dewatering system. Fine soil particles were being carried by the water leaking into the pipe, then being flushed away downstream. The extent of soil disturbance was eventually determined using feedback from compaction grouting operations such as drill penetration rates, grout injection volumes and injection pressures.

Within a 19 m x 22 m area and targeting the disturbed sandy layer 6 to 8 m below depth, 120 m^3 of low mobility compaction grout was injected. Figure 5 shows the compaction grouting in progress inside a shored excavation. The primary 71 no. holes were spaced at 2 m center-to-center spacing and were drilled 10 m deep. These primary holes consumed 90 m^3 of grout.

A total of 30 no. secondary holes were drilled and grouted, located strategically between primary holes where large volumes of grout had been injected. Drilling was completed using two drills running non-percussive, double-head duplex tooling. Grout was delivered to site by ready-mix truck.

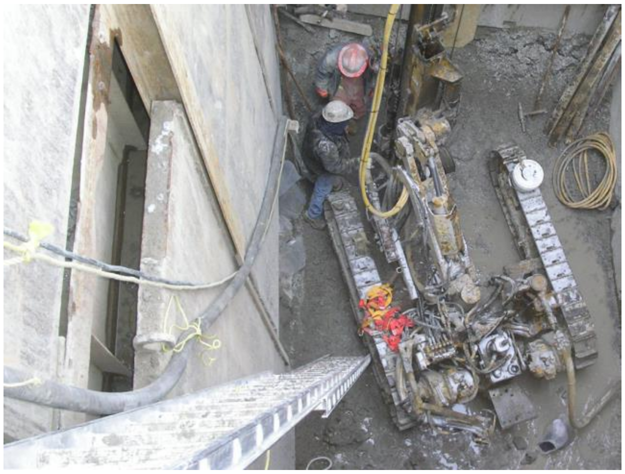

Figure 5 Compaction grouting in progress inside a shored excavation

4 ROCK FISSURE GROUTING

4.1 Application

Rock fissure grouting is typically performed in fissured rock masses to reduce the flow of water along the joints and discontinuities in the rock. A hole is drilled through the fissures and joints of a rock mass and grouted. The grout travels along the discontinuities and seals them to control ingress and flow of water, along the sealed discontinuities.

4.2 Design and execution considerations

Most rock fissure grouting is performed with cement- based grouts although a number of chemical grouts exist for low permeability rock or to achieve high-performance criteria. Most grout curtains include a base design and contingency for higher order holes allowing for the data obtained during the execution of the work to govern final design (Kirsch and Bell, 2013).

In the case of cement-based grouts, it is imperative that the grout is stable (low bleed) with appropriate pressure filtration characteristics. The viscosity of the grout must be adjustable by using additives and other mix design variations. High water to cement ratio grouts (unstable and high bleed) are not appropriate for permanent cut-off walls. These grouts will become unstable at high injection rates causing premature refusal of the fractures and will exhibit bleed within the fracture leaving residual pathways. Figure 6 shows a schematic of rock fissure grouting.

Design considerations for a grout curtain include:

- Depth of treatment
- Number of rows of grout holes required (typically 1 to 3).
- Spacing of primary holes
- Order of holes to be mandatory
- Criteria for going to the next order of holes
- Refusal criteria (pressure and flow rate)
- Stage length
- Other project specific requirements

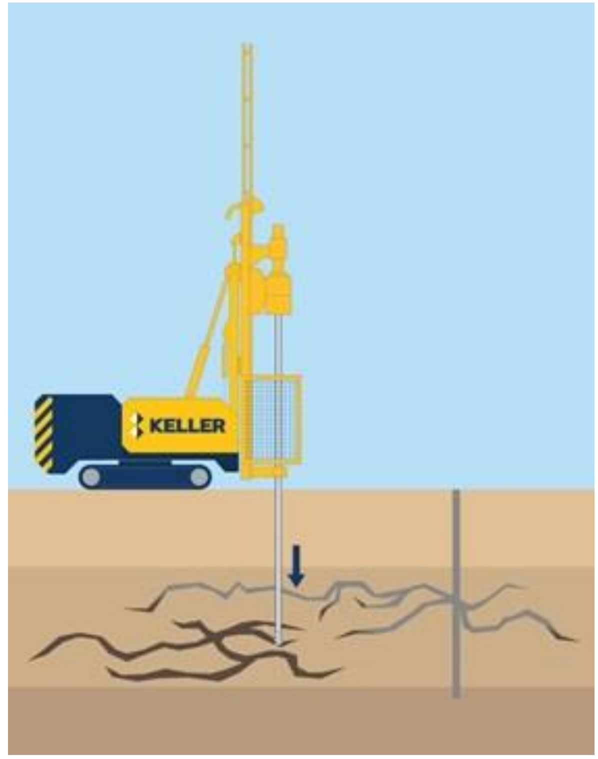

Figure 6 Schematic of rock fissure grouting

Grout curtains are created using a split spacing system whereby primary holes are drilled and grouted over a given area before drilling and grouting secondary holes and so on. In this manner, the hydraulic conductivity of the formation is progressively reduced. It is common practice to record and display all grouting in real-time to allow effective real-time adjustments to the grouting program including adjustments to flow, pressure and mix design.

Rock drilling is typically performed with standard rock drill rigs or core drills and water flush to aid in the evacuation of cuttings. For deeper applications and higher production rates, water actuated hammer drilling methods can prove effective. Water pressure testing of some of the holes in advance of grouting can aid in developing an effective design and mix design considerations.

Cement grouts should always be prepared using high shear/high speed (colloidal style) mixers to ensure complete wetting of the cement particles and thus improving injectability. Grout is injected through grout lines and mechanical or inflatable packers are used to isolate zones in the rock. A return line system is typical to permit control of flow and pressure with the flowmeter and pressure transducers located downstream of the return line system.

Common applications of rock fissure grouting include:

- Grout curtains beneath new or existing dams
- Water cut-off of excavations in rock (walls and base)
- Water cut-off in advance of tunneling operations
- Strengthening of foundation rock beneath structures
- Improvement of rock for piles or anchors

4.3 Case history: Rock fissure grouting at Bruce Nuclear Generating Station near Tiverton, Ontario

At Bruce Nuclear Generating Station near Tiverton, Ontario, the construction of a deep geologic repository (DGR) was being considered by Nuclear Waste Management Organization (NWMO) for the long-term storage of low and medium level radioactive waste.

As part of the feasibility study for the DGR, rock drilling and grouting of 200-metre deep holes for Phase 1 of a deep grouting trial was executed to determine parameters for the pre-treatment of the underlying rock formation prior to excavation of the proposed DGR shafts.

Pre-grouting of the rock is necessary to permit excavation under controlled inflow conditions. Phase 1 of the grouting trial was carried out to test and establish drilling and grouting methods specific to this site.

With the consultant having placed considerable importance on the drilling accuracy at depth (with a specified tolerance of 0.5 degrees, or ±1.0 m in plan at 200 m depth), two drilling methods were tested: Wassara water hammer system and Navidrill (directional coring), chosen specifically for their ability to drill straight, clean holes. Figure 7 shows the equipment used for drilling.

Figure 7 The equipment used for drilling

Gyro survey methods were used to periodically check hole alignment and determine when corrections were required, at which point the Navi-Drill system was utilized to make minor hole alignment corrections to maintain the required tolerance. Prior to grouting, an acoustic televiewer was used to supplement the water test data in order to better establish the nature of the rock fractures.

Phase 1 of the test program ultimately consisted of 3 no. primary holes and 1 no. secondary/verification hole each having been drilled, water tested and grouted. The successful implementation of Phase 1 resulted in the decision to proceed with Phase 2.

Lessons learned from Phase 1 were implemented to improve productivity and mitigate risks. A total of 10 no. holes, arrayed in a ring, were advanced to a target depth of 200 m below existing grade and grouted in stages. Water hammer drilling was used for all of the phase 2 grout hole drilling work. The same grout mixes established during Phase 1 of the trial program were used.

A key objective of the surface-based grouting trial was to evaluate the ability to control water inflows during shaft sinking. Phase 2 of the deep grouting trial included installation of overburden casings, drilling of rock, water pressure testing and grouting of the drilled holes. Grout holes were drilled using a water-actuated Wassara down-the-hole water hammer on a stabilized drill string. Alignment surveying of each grout hole was performed to full depth prior to final upstage grouting.

Based on lessons learned and previous conditions encountered in Phase 1, downstage sequencing of the grouting was implemented to prescribed depths on the 5 no. primary holes. The drilling and grouting program was continuously evaluated and modified based on drilling and water pressure testing data. Real-time grout monitoring software tailored specifically to this project was developed and utilized. Drilling data was recorded using the Jean Lutz LT3 system. Both drilling and grouting reports were generated after the end of each shift and provided to the Owner's representative.

Upon completion of all drilling and grouting activities, pumping tests were carried out to provide hydrogeologic data in support of the grouting program. The pump well was installed at the center of grout ring to a depth of 120 m below existing grade. Multilevel vibrating wire piezometers were installed at radial distances of 3 m, 20 m and 40 m from the center of the grout ring. The pump test demonstrated that grouting reduced the permeability of the rock mass to acceptable levels. All objectives of Phase 2 of the deep grouting trial were satisfied.

5 PERMEATION GROUTING

5.1 Application

Permeation grouting is the process of injecting grout (chemical or suspension) in sands and gravels with fluid grouts to produce sandstone like masses by filling the voids to attenuate water flow. Grout can be made of sodium silicate, acrylates, polyurethane and micro fine cement and regular cement grout (CFEM, 2006).

Multiple port sleeve pipes (MPSP) should be installed in a certain pattern in drilled holes with the annulus filled with a low-strength cement-bentonite grout. Grout can be injected through ports with design intervals and rates to permeate the treatment area. Permeation grouting is suitable for cohesionless soils, especially for clean sands and gravels. With the increase in the fine content, the connectivity of soils' pores reduces and therefore the effectiveness of the permeation grouting reduces consequently. Permeation grouting is more suitable for utility support, groundwater control and tunneling. Figure 8 shows a schematic of permeation grouting.

5.2 Design and execution considerations

Geotechnical information is critical when designing a soil grouting program. Detailed sieve analysis that is representative of the target zones is required to determine types of grout to be used, anticipated grout spread and to establish whether permeation grouting is applicable.

The process and principles of permeation grouting are similar to rock fissure grouting however with the added complication that a reliable conduit must be created for controlled injection in stages. In rock grouting, open hole drilling is typically possible and grout stages are isolated with packers working in an up-stage sequence. For soils, an open hole must be created to allow the installation of a multiple sleeve port pipe (tube a manchette). This sleeve pipe becomes a conduit for controlled and repeatable injection. The sleeve pipe is a pipe with a series of holes installed and protected with a rubber sleeve. The annular space between the temporary hole diameter and the sleeve pipe is filled with a weak cement-bentonite grout. Once this is created grouting can take place in an open conduit using double packers to isolate sleeves. The weak grout is easily fractured permitting grout access to the soils. If the integrity of the sleeve pipe is maintained and it is flushed out, grouting can be repeated multiple times in the same sleeves to systematically reduce the permeability of the soil while controlling the grout spread.

Some common applications of permeation grouting include:

- Strengthening and reducing permeability of earth dams
- Strengthening soils beneath sensitive structures
- Stabilizing soils in advance of excavation adjacent to or beneath sensitive structures
- Reducing inflows into excavations through soils
- Environmental cut-off walls isolate contaminated zones

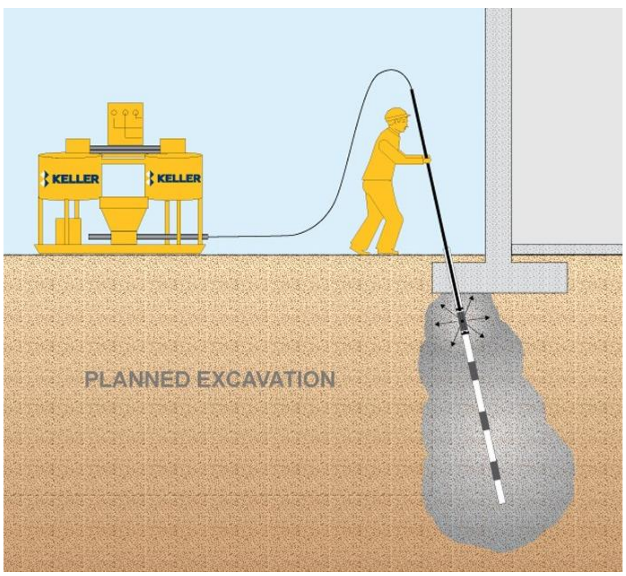

Figure 8 Schematic of permeation grouting

5.2 Case history: Permeation grouting at Rideau Regulator Chamber, Ottawa, Ontario

One component of the City of Ottawa's ongoing strategy to upgrade its critical infrastructure is the improvement of several overflow chambers making up a part of the City's combined storm/sanitary sewer system. Expansion of the existing Rideau Regulator Chamber, buried deep beneath grade at the foot of the stepped walkway connecting historic Rideau Canal with Canada's parliament buildings posed a unique set of challenges to the City's Engineers due to existing conditions above and below grade.

The chamber is located beneath a narrow strip of land in the shadow of the Plaza Bridge that had to be kept open to pedestrian access. Below grade, the chamber is 14 m deep, extending deep into bedrock, but is surrounded by debris-rich, loose sand fill and a high water table.

Grouting at this site was specified to achieve two goals: adequately stabilize the fill soils to the extent necessary to facilitate safe excavation for construction of the expanded chamber, and for the long-term mitigation of risk to the sewer system from potential future seismicity. Permeation grouting, employing both suspension and solution grouts, was designed and constructed over two phases in the spring and autumn of 2008. Figure 9 shows the set-up for permeation grouting at the site.

Figure 9 Permeation grouting at Rideau Regulator Chamber

Double-head rotary duplex drilling process was used to temporarily case the holes to depth in order to install tube-a-manchette sleeve pipes. The drilling had to be successfully advanced through sand, silt and bedrock ledges underlain by more sand fill, as well as several concrete, wood and steel obstructions.

Sleeve pipes for permeation grouting were arranged on a 1 m center-to-center grid spacing and varied in depth from 6 to 14 m. In total, 34 no. sleeve pipes were installed for grouting; an additional 3 no. sleeve pipes were installed at select locations to assess the in-situ permeability of the target soil mass before and throughout the grouting work. Grout was injected in multiple passes over several days. Microfine cement grout was injected in the first pass, but only through sleeve pipes that were not within the footprint of the proposed excavation. All grout holes were injected with two passes of sodium silicate solution grout. In total, over 4500 L of microfine cement grout and more than 46000 L of sodium silicate grout were injected into the soil mass. There were 444 no. targeted sleeves, averaging 115 L of grout injected per sleeve. Real-time monitoring and recording of grout flow vs. time and pressure vs. time were employed throughout the work.

Comparison of hydraulic conductivity testing results from before and after grouting showed a reduction of permeability in the soil mass greater than one order of magnitude. The ultimate success of the grouting program was proven when the grouted soil remained self-supporting upon excavation throughout the entire advance of the temporary steel liner to 14 m depth. A very minor amount of water seepage was observed during excavation, but its source was determined to be the untreated bedrock.

6 SUMMARY

An overview of a few grouting methods which are different in process and application are briefly described in this paper. The methods can be designed to:

- Destroy and blend the soil matrix (jet grout erosion)
- Displace and stabilize the soil (compaction grouting)
- Penetrate the pore space of soils and fractures of the rock (rock fissure and permeation grouting)

All methods can change the native soil properties through improved strength and reduced hydraulic conductivity. Each method has its particular pros and cons for a given challenge to be overcome. All project constraints and objectives must be assessed along with the existing ground conditions to determine the most appropriate grouting technology and design/application of that technology.

This discussion has been very brief and general in nature and should only be considered as an introduction to a few of grouting technologies available today.

7 REFERENCES

Canadian Foundation Engineering Manual -CFEM (2006), Canadian Geotechnical Society Fourth Edition.

Kirsch, K. and Bell, A (2013), Ground Improvement, Third Edition, CRC Press.